1998-03

A tradeoff analysis of Just-In-Time and non Just-In-Time inventory with transportation ramifications

Braga, Ataide R.

Monterey, California. Naval Postgraduate School

http://hdl.handle.net/10945/32710

NAVAL POSTGRADUATE SCHOOL
MONTEREY, CALIFORNIA

THESIS

A TRADEOFF ANALYSIS OF JUST-IN-TIME AND NON JUST-IN-TIME INVENTORY WITH TRANSPORTATION RAMIFICATIONS

by

Ataide R. Braga

March 1998

Thesis Advisor:	Jane N. Feitler
Associate Advisor:	James E. Suchan

REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE March 1998	3. REPORT TYPE AND DATES COVERED Master's Thesis

4. TITLE AND SUBTITLE A TRADEOFF ANALYSIS OF JUST-IN-TIME AND NON JUST-IN-TIME INVENTORY WITH TRANSPORTATION RAMIFICATIONS	5. FUNDING NUMBERS
6. AUTHOR(S) Ataide R. Braga	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.	12b. DISTRIBUTION CODE

13. ABSTRACT *(maximum 200 words)*

The purpose of this research is to investigate when a Just-In-Time (JIT) inventory management technique is a worthwhile approach to managing inventories. Some experts in the field maintain that the additional transportation costs derived from using JIT and its costs due to frequent shipping is more than offset by the reduction in inventory levels. In this study a simulation is developed using the cost structure of Naval Air Station Lemoore for managing a selected group of items. Lemoore is considered the Inventory Control Point and the Stock Point for those items. Research results indicate that despite all the advantages of using JIT, JIT is not always the lowest cost approach. Recommendations are that inventory managers delineate the associated costs using each technique and perform a thorough analysis that compares the two alternatives, and that JIT is not a general solution leading to the lowest cost for management of all inventory items.

14. SUBJECT TERMS Just-In-Time, Transportation Cost, Holding Cost, Break-Even Point, Trade-off Analysis, Contrasting Cost Structures	15. NUMBER OF PAGES 74
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18 298-102

Approved for public release; distribution is unlimited.

A TRADEOFF ANALYSIS OF JUST-IN-TIME AND NON JUST-IN-TIME INVENTORY WITH TRANSPORTATION RAMIFICATIONS

Ataide R. Braga
Commander, Brazilian Navy
B.S., Brazilian Naval Academy, 1979

Submitted in partial fulfillment
of the requirements for the degree of

**MASTER OF SCIENCE
IN
MANAGEMENT**

from the

NAVAL POSTGRADUATE SCHOOL
March 1998

Author: [redacted]
Ataide R. Braga

Approved by: [redacted]
Jane N. Feitler, Thesis Advisor

[redacted]
James E. Suchan, Associate Advisor

[redacted]
Reuben T. Harris, Chairman
Department of Systems Management

ABSTRACT

The purpose of this research is to investigate when a Just-In-Time (JIT) inventory management technique is a worthwhile approach to managing inventories. Some experts in the field maintain that the additional transportation costs derived from using JIT and its costs due to frequent shipping is more than offset by the reduction in inventory levels. In this study a simulation is developed using the cost structure of Naval Air Station Lemoore for managing a selected group of items. Lemoore is considered the Inventory Control Point and the Stock Point for those items. Research results indicate that despite all the advantages of using JIT, JIT is not always the lowest cost approach. Recommendations are that inventory managers delineate the associated costs using each technique and perform a thorough analysis that compares the two alternatives, and that JIT is not a general solution leading to the lowest cost for management of all inventory items.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

I. INTRODUCTION

A. BACKGROUND

The ability of a firm to effectively manage its inventory is often one of the primary determinants of the firm's success. Raw material and purchased parts inventories are needed to produce the finished goods, work-in-process inventories are needed to keep the production facility going, and finished goods inventories are needed to supply customers. If inventories are properly managed they can result in increased sales, improved productivity, increased service level, reduced production and distribution costs, and increased profits.

Recently, due to the increasing costs of capital and increased competition, managers responsible for inventory control have been under pressure to reduce inventories to a minimum, while at the same time they must provide sufficient inventories to assure high levels of customer service.

In order to achieve significant reductions in inventory, several companies have adopted the Just-In-Time (JIT) approach as their primary inventory management technique. In a broad sense, the term Just-In-Time describes a manufacturing philosophy in which the right amount of raw materials arrive at a designated place at the exact time to meet demand. JIT is also frequently used interchangeably with "zero inventory." In both cases the JIT approach attempts to virtually eliminate all costs that do not add value to the product.

Previous research, by the General Accounting Office (GAO) has shown that the Department of Defense (DOD) has too much inventory on hand [Ref. 1]. Because of the DOD's longstanding inventory management problems, DOD inventory management is on GAO's list of high-risk federal program areas that are especially vulnerable to waste, fraud, and mismanagement.

In 1992 GAO reported that DOD had wasted billions of dollars on excess supplies. The research concluded that the problem results from DOD's culture where it was better to overbuy items than to manage with just the amount of stock required [Ref. 2]. In 1995, the GAO reported that half of DOD's secondary inventory, valued at $ 69.6 billion dollars, was not required to be on hand to support war reserves or operating requirements [Ref. 3].

The GAO has repeatedly suggested that the DOD should make more use of commercial practices as a way to reduce inventory levels. Those private sector approaches include (1) using Just-In-Time business practices that shift responsibilities for storing and managing inventory to suppliers, (2) shifting responsibility for managing items to suppliers through the use of long-term agreements with only a few key suppliers, (3) using local distribution centers and an integrated suppliers program to improve consumable item support and reduce "just-in-case" inventory.

However, a highly reliable transportation system has been identified as a key success factor of JIT inventory management. Additionally, JIT techniques have a significant financial impact on transportation due to the increased number of shipments.

Some experts maintain that inventory costs have skyrocketed over the past years, despite a decline in global interest rates. Between 1975 and 1993, inventory costs rose 88.2 percent on a relative basis as opposed to a 17.6 percent increase in the cost of maintaining warehouses and a 20.7

percent decline in transportation costs [Ref. 4]. Consequently, experts maintain that companies should identify the point at which their cost of carrying inventory exceeds the cost of shipping that inventory.

B. RESEARCH INTENT

In response to several recommendations provided in GAO reports, this thesis will investigate when JIT inventory management is a worthwhile approach. In order to do that, this research will develop a tradeoff analysis between JIT and non-JIT inventory management for a selected set of ready-to-issue military aircraft parts. The research will consider, as the major drivers in this analysis, inventory holding costs, also called carrying costs, under a non-JIT approach, in contrast to transportation costs as a result of using the JIT technique.

C. SCOPE OF THE THESIS

The study is divided into two parts. First, a brief discussion of the variable costs associated with traditional inventory management technique is presented followed by an overview of the principal aspects involved in the JIT philosophy.

Second, the research focuses on the analysis of a group of selected, non-classified, ready for issue, off-the-shelf, and non-repairable items whose lack of availability degrades the readiness of military aircraft. This study will not deal with private sector, U.S. Army, and U. S. Air Force spare parts.

D. METHODOLOGY

Extensive archival research was conducted through books, magazine articles, CD-ROM Systems, and the Lexis/Nexis Database available at the Naval Postgraduate School Library. Additionally, a comprehensive review of the Defense Logistics Studies Information Exchange Database was performed with emphasis on Just-In-Time techniques and related mathematical models. Lastly, government literature and publications published by the General Accounting Office were examined.

Personal interviews were conducted during an on-site visit to the Naval Air Station Lemoore, California. Key personnel involved in those interviews were the Supply Officer and the Director of the Aviation Support Division. Telephone interviews were conducted with the suppliers of the selected group of items.

All the information gathered through the research described above was instrumental in building a baseline assessment to document the tradeoff analysis and develop a set of recommendations.

E. ORGANIZATION OF STUDY

To provide the reader with background information about the costs to manage inventories under a non-JIT environment and the philosophy of JIT inventory management technique, an in-depth literature review is introduced in Chapter II. In Chapter III the data gathered to support this research is presented.

Chapter IV delineates the mathematical model used as a guide for the author's research and findings. The final chapter presents conclusions and recommendations.

II. LITERATURE REVIEW

A. CHAPTER OVERVIEW

The purpose of this chapter is to introduce the variable costs in purchasing, and stocking decisions associated with inventory management of secondary items[1] under a non-JIT environment. These costs are also called demand-based items because their demand can be forecasted. In addition, the chapter provides a quick overview of JIT philosophy evolution and addresses issues related to the JIT concept, principle elements, costs, benefits, and results of some successful implementation of this methodology.

B. DEFINING COSTS IN MANAGING INVENTORIES UNDER A NON-JIT ENVIRONMENT

1. Ordering Costs

Ordering costs reflect the expenses associated with purchasing and receiving orders for the replenishment of inventories [Ref. 6, p. 413]. DOD Instruction 4140.39 defines this type of expenditures as:

> Those costs associated with the determination of requirements processing request, and subsequent contract action through receipt of the order into the inventory control point system that will vary significantly in relation to the number of orders processed. [Ref. 7, Encl. 3]

---

[1] Secondary items are minor end items which include replacement, spare and repair components; and personal support and consumable items. Examples of those items are aircraft and ship components; medical and construction supplies; and food, clothing, and fuel. [Ref. 5]

Consequently, to determine ordering costs, DOD requires the services to analyze labor and computer-processing costs, which include generation of purchase request, solicitation evaluation, contract administration, material receipt, payment, communications, documentation, and indirect personnel.

2. Holding Costs

Holding costs are the costs of having inventories of material on hand to distribute to meet customer demand. DOD expresses this expense as a percentage of the value of average on-hand inventory during annual operation. It is assumed that this cost is linear due to the constant holding cost rate applied over the average inventory figure.

The table below depicts the elements of this kind of expenses for consumable items for a majority of Navy applications [Ref. 5, p. 36].

Table 1. Holding Cost Rate

Time Value of Money	10%
Warehousing	1%
Obsolescence	10%
Theft and Shrinkage	2%
Total	23% per year

a. *Time Value of Money*

The time value of money or investment charge is associated with the cost of having capital tied up in inventories instead of being used in some other investment. The economists call such an occurrence as the opportunity cost of money.

b. *Warehousing*

Warehousing is defined in DOD Instruction 4140.39 as cost of storage.

The cost of storing the inventory itself includes: care of material in storage, warehousing costs, cost of physical inventory operations, preservation and packaging, training of storage personnel, cost of warehousing equipment and pro-rated base services and overhead costs. The sum of these annual costs divided by total average on-hand inventory, all on-hand assets as opposed to applicable assets, gives the out-of-pocket storage cost rate. The facilities cost rate is added to the above to give the total storage cost rate.

c. *Obsolescence*

Obsolescence is the holding cost element associated with the amount of inventory that becomes superfluous due to technological changes, over-forecasting requirement, deterioration in its original characteristics [Ref. 7].

d. *Theft and Shrinkage*

This component is associated with inventory losses due to pilferage, shrinkage, and inventory adjustments. It is calculated as a fraction of total assets as pointed out in the equation below:

$$\text{Theft and Shrinkage} = \frac{\text{Net Losses in Inventory}}{\text{Total Assets}}$$

3. **Stockout Costs**

Stockout costs are the economic consequences of not having a particular item in stock when the customer places an order. This variable is hard to measure because it depends on the customer reaction to the shortage.

If back orders are allowed, the customer will wait until the next inventory replenishment. If not, a sale will be lost and the cost identifiable in this case ranges from the apparent profit loss on the sale to loss of goodwill. [Ref. 8, pp. 14-15]

DOD Instruction 4140.39 and more recently the Material Management Regulation [Ref. 10], does not provide guidance in estimating stockout costs.

C. JUST-IN-TIME PHILOSOPHY

1. Historical Overview

The JIT idea began in 1921 with Henry Ford's vision of implementing this manufacturing technique in his Highland Park and River Rouge factories. Ford developed a production rate of one Model-T car every four days in the River Rouge factory. The production cycle started with the input of required steel at a mill located in the plant geographical area and ended with an automobile ready for sale. [Ref. 10, pp. 9-10]

Furthermore, this methodology gained a new dimension after World War II when Japan developed some form of JIT inventory practices resulting from their search for ways to improve their products' quality and manage the scarce resources available after a war which had devastated the country's assets.

During the 1960's Dr. Edward Deming exported his management style of thinking toward improving the quality of the products, which indirectly ended up contributing to the development of JIT. Dr. Deming traveled extensively in Japan to promote the concepts of Total Quality Control (TQC) to that country's leading industrialists. TQC emphasized decreasing inventory levels through smaller lot sizes, thus reducing work-in-process inventories. Consequently, JIT became a sub-product of a firm reengineering process using Dr. Deming's 14 points for implementing quality improvement, which are listed on Table 2.

The Toyota Production Plant first implemented the technique of JIT manufacturing in the early 1970's. The goal

Table 2. Deming's 14 Points

1	Create consistency of purpose
2	Lead to promote change
3	Build quality into the product; stop depending on inspections to catch problems
4	Build long-term relationships based on performance instead of awarding business on the basis of price
5	Continuously improve product, quality, and service
6	Start training
7	Emphasize leadership
8	Drive out fear
9	Break down barriers between departments
10	Stop haranguing workers
11	Support, help, and improve
12	Remove barriers to pride in work
13	Institute a vigorous program of education and self-improvement
14	Put everybody in the company to work on the transformation

From Ref. [19]

was to meet customer demands with minimum delays. Mr. Tai-Schi Ohno, who was the company's President at that time, is frequently referred to as the father of JIT. [Ref. 11, p. 2]

Ohno's development is called a Pull Inventory System which is a totally different approach of manufacturing material flow when compared to the traditional Push Inventory Management System. Under the Pull System, the flow of material into a down-stream department is "pulled" from the upstream department as needed. The upstream department cannot produce parts unless a down-stream department requires them. Consumer demand for products establishes the output of the final departs down on the line. In practice, the throughput of the manufacturing process is based on the capacity of these final departments. Hence, items are manufactured just-in-time to meet demand, and sub-assemblies are produced just-in-time within the manufacturing process itself.

Under the Push Inventory System, upstream departments continually make parts, without considering the customer demand of this final product, and pass them along to the down-stream departments for further processing. If the departments down on the line do not have capacity to process all the incoming sub-assemblies, they will be sitting in transit areas waiting to be processed. In other words, work-in-process is going to build up.

2. JIT Concept

Although the JIT philosophy and supporting techniques were developed mostly in Japan, many of the concepts are no longer specifically Japanese. Although applied mostly to manufacturing, the concepts are not limited to this area of the business. Purchasing and inventory control are some examples where this technique can be utilized.

Essentially, JIT is the elimination of waste by producing and delivering finished goods just-in-time to be sold, sub-assemblies just-in-time to be assembled into finished goods, fabricated parts just-in-time to go into sub-assemblies, and purchased materials just-in- time to be transformed into fabricated parts. In other words, JIT disseminates the idea of having the right material at the right time, the right amount, and in the right place. [Ref. 12, p. 16]

In summary, the JIT concept calls for continually decreasing total inventory levels by decreasing the lot size, and thus the amounts of buffer stocks, work in process, and in-plant inventory. Similarly, it pursues waste reduction by allocating the appropriated resources of material, machines, and manpower to the production process.

3. Elements of JIT

As an extension of the above concept, one can list the focus of JIT as:

- Inventory reduction;
- Process improvement; and
- Elimination of waste.

a. *Inventory Reduction*

JIT emphasis is on minimum lot sizes, close to one unit at a time, and frequent deliveries. In fact, parts are not allowed to accumulate. Some authors believe that this procedure contributes for tight inventory and quality control. They also say that the associated increase in transportation costs and lost freight discounts caused by JIT are outweighed by the improved product quality and decrease in carrying costs. [Ref. 15, p. 84 and Ref. 4]

b. *Process Improvement*

As a result of the inventory reduction, some production problems, normally hidden by excess stocks, will be exposed earlier, thus demanding quicker management actions. The elimination of those problems will result in process improvement. [Ref. 13, pp. 16-17]. Figure 1 illustrates the discussion presented above. The inventory level is represented by the water and the rocks represent process problems. Consequently, high inventory levels can hide a wide range of productivity and production problems.

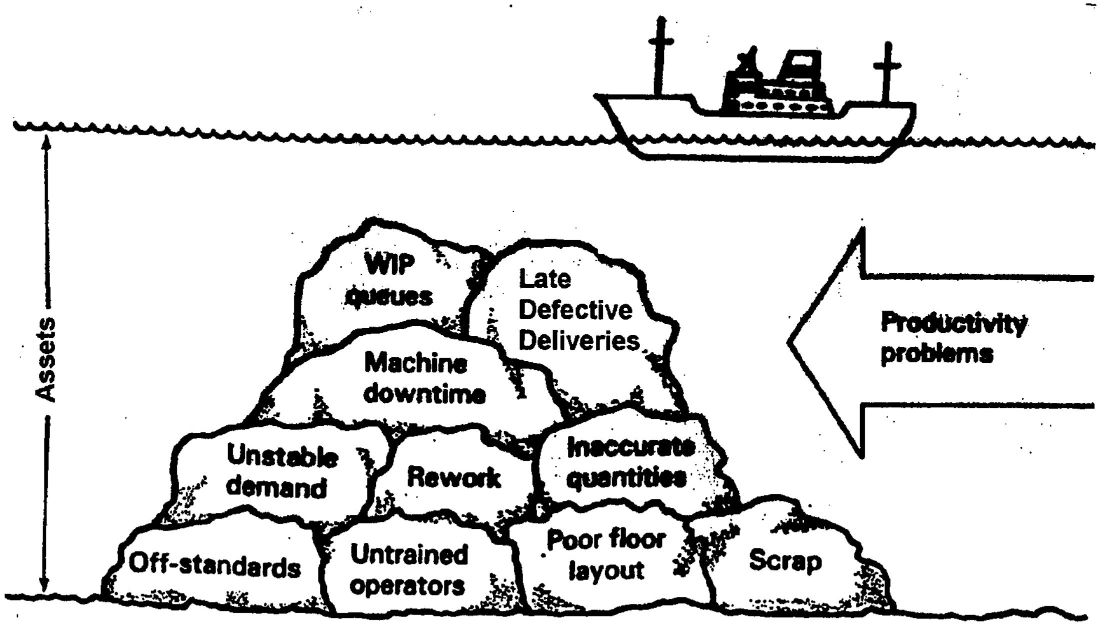


Figure 1. Some Production Problems
From Ref. [14]

c. *Elimination of Waste*

From a production perspective, JIT attempts to reduce and even eliminate activities which add cost and do not add value to the product. Toyota identified seven wastes as follows: [Ref. 14: p. 34-37]

> **Overproduction** - Produce only what is needed now, finished goods cost money to store.
>
> **Waiting Time** - Synchronize the production line to avoid congestion in one point and idleness in others.
>
> **Transporting** - Unnecessary handling of materials adds cost to a product.
>
> **Processing** - Some processes are themselves a waste, so any unnecessary process should be eliminated.
>
> **Stock on Hand** - The cost of extra raw materials increases the total cost of an operation.

Motion - Simplification of work and reduction in the waste of motion decrease costs because the tasks are performed in less amount of time.

Defective Goods - Defective products increase costs by wasting materials.

d. Supplier Relationship

Under JIT there is a purchasing perspective that leads to inventory reduction -- a strong, committed relationship with suppliers that enables the company to have the right material at the right time. To accomplish this goal, inventory managers should reduce the number of suppliers with whom they work and build long-term relationships supported by long-term contracts. The suppliers, on the other hand, must make a commitment to flexibility in delivering small quantities within narrow time frames and provide a high quality product.

Contracts should not be awarded to suppliers based on the lowest bidder criteria. They should be based on the suppliers who can consistently provide a high quality product which eliminates the need for inspection on the buyer's dock, are willing to work with the buyers to solve problems, and can meet a rigid delivery schedule. [Ref. 15, pp. 29-38] Table 3 summarizes the expectations between the suppliers and buyers in a JIT System.

5. The Role of Transportation

Transportation is a critical element in any JIT System and is called on to perform at a level of efficiency and dependability which is much greater than that required in traditional logistics systems where buffers of inventory essentially decouple the transportation system from the operations of the firm.

Table 3. Expectations of Buyer and Supplier in a JIT System

Expectations of the JIT Supplier	Expectations of the JIT Buyer
Long-term business partnership	High quality parts that meet requirements consistently
Fair profits and return on investment	Short lead-times
Fair dealing	Fair dealing
Single sourcing	Quality of parts and service sufficient to dispense with inspections and buffer inventories
Accurate forecasts and timely notice of changes	Cost reductions and learning curve savings passed on to the buyer
Clear and accurate parts specifications	Quick resolution of quality problems
Minimum order changes	Frequent communication
Prompt payment of invoices	
Good technical support	
Quick feedback on quality problems	
Frequent communication	

From Ref. [14]

The characteristics listed above are going to be achieved with a more flexible, faster, and more expensive transportation mode: air transportation. Therefore, the greater use of air transportation due to frequent shipments in a JIT System will raise the firm's transportation costs. However, several firms interviewed by Harper and Goodner found that the higher transportation costs were more than offset by lower inventory carrying costs. [Ref. 16, pp. 22-31]

6. Benefits of Implementing JIT

Some of the benefits have already been addressed in this chapter. The following is a consolidated list of those advantages and others:

Lower Costs to Hold Inventory - The most obvious benefit in reducing stock levels with JIT is lower costs in holding fewer items and reduced warehouse space requirements.

Lower Capital Investment Inventory - With lower stock levels, less money is tied up in stock at any one time.

Quality Improvement - Fast detection and correction of unsatisfactory quality are performed promptly after the items are received, resulting in high quality of purchased parts.

Administrative Efficiency - Fewer suppliers with long-term commitments improve relationships, minimize follow-up procedures, simplifies communications and reduces paper work.

Lower Administrative Costs - High quality parts reduce the need for inspections, eliminates discrepancy reports, and reduces delays due to non-availability of parts.

7. Success of JIT Implementation

A review of JIT literature points out two examples of achieving improvement through an efficient and effective JIT implementation.

- **Omark Industries** - Omark Industries has applied its own version of JIT, called "ZIPS" (Zero Inventory Planning), to its 21 plants. On average, total inventories were reduced from 45 to 55 percent, lead times fell from 30 days to a matter of one day, and work-in-process went from 60 pieces to only one. [Ref. 17, p. 744]

- **Sandia National Laboratories** - The JIT Program has eliminated $ 7.2 million worth of inventory that was carried in Sandia's warehouse. This inventory was transferred to local distributors servicing Sandia, which contributed to a reduction of $ 720,000 a year on inventory carrying expenses. As a result of this elimination of inventory, 20,000 square feet of warehouse space has become available for other uses.

> Additionally, labor savings of $ 2.3 million a year were achieved through the elimination of warehousing and servicing tasks. [Ref. 18, p. 66]

D. CHAPTER SUMMARY

This chapter provided information regarding the variable costs associated with managing inventory under a non-JIT environment. Ordering costs are a function of the set of procedures used to perform the tasks of stock requisitioning, receiving, stowage and issue. Holding cost is the cost associated with holding stock in inventory for later issue.

The chapter has presented an historical snapshot about how the JIT philosophy evolved through the years and addressed issues related to the JIT concept, principal elements, costs, benefits, and results of some successful implementations of JIT.

The next chapter will present the data used in this study and the methods used to gather the data.

III. DATA

A. CHAPTER OVERVIEW

The previous chapter addressed the variable costs associated with managing inventories in a non-JIT environment, for example, holding cost and ordering costs. Chapter II presented some aspects of the JIT philosophy and its emphasis on smaller lot sizes and frequent shipments when the JIT technique is adopted for managing inventories.

This chapter presents the data used in this study of the two inventory management approaches. The data is presented with the perspective of the cost realized by each one of the inventory methods when it is used to manage a group of selected items. It is being used to mathematically check if JIT is really a worthwhile alternative to a non-JIT environment.

B. THE SELECTED ITEMS

This study focuses on a set of ready-to-issue, non-repairable military aircraft parts that degrade the FA-18 aircraft readiness condition. These items are consumable parts that directly affect the FA-18 operation availability if the ground support group does not have the item when required. The items used in this study are classified in either one of two sub-sets.

The first sub-set of items are classified as "Not Mission Capable Supply" (NMCS). This means that the aircraft is not able to accomplish any mission unless this item is available to repair the aircraft.

The second sub-set of items are categorized as "Partially Mission Capable Supply" (PMCS). This indicates that the aircraft may be used without these items being available for repair of the aircraft. But the aircraft will not be capable of accomplishing all missions that may be assigned. [Ref. 20]

Table 4 shows a sample of the items that are the focus of this study. The data are collected from Commander StrikeFighter Wing Atlantic. This data was also confirmed by the Naval Air Station Lemoore as being the "heavy hitters" consumable items for the multi-role FA-18 Hornet aircraft. The Lemoore annual demand for the sample in evidence is the fundamental source of data in developing this examination.

C. ANNUAL DEMAND FOR THE TOP DEGRADERS

Naval Air Station Lemoore is the home base for nine FA-18 fleet units on the West coast. Three units are permanently forward deployed and home ported in Japan, or aboard the carrier USS Independence (CV 62). This study bases its trade-off analysis on data from NAS Lemoore Aviation Support Division. In this study NAS Lemoore will be considered the Inventory Control Point.[2] It also serves as Stock Point[3] for the items listed in Table 4. Instrumental in this analysis is the annual demand showed by the nine FA-18 fleet units supported by the Aviation Division. Table 5 depicts these figures [Ref. 21].

---

[2] Functions of an Inventory Control Point are: integrated inventory management; requirements determination; material distribution and issue; material procurement; budget development for parts support [Ref. 5].

[3] The main mission of a stock point is the physical distribution of material. The main functions include: receiving material; stowing material; issuing and shipping material; billing the customer for material; budgeting and accounting for funds to procure material; reporting receipts and issues to each item's SCP [Ref. 5].

Table 4. Heavy Hitters

National Stock Number (NSN)	Nomenclature	Part Number	CAGE	Degrade To
5945-01-138-5529	Electromagnetic Relay	BH-420D	74063	NMCS
6685-01-123-5112	Pressure Indicator	3809414-2	55972	NMCS
6620-01-151-0620	Pressure Transmitter	3135-8603	99564	NMCS
5930-01-115-7338	Proximity Switch	8-321-03	08748	NMCS
5310-01-132-3395	Self-locking Nut	SL405-12F	97393	NMCS
5315-01-138-0797	Hollow Pin	74A480619-2001	76301	PMCS
3120-01-121-1798	Sef-aligning Bearing	74A410708-1001	76301	NMCS
1560-01-407-1861	Wing pin	74A230684-1003	76301	NMCS
3040-01-125-8207	Connecting Link	74A180696-1001	76301	NMCS
1680-01-140-3889	Gearbox Assembly	74A542010-1007	76301	NMCS
1560-01-166-3331	Manifold Fluid	74A586952-1017	76301	NMCS
5310-01-168-4489	Recessed Washer	4M276-1	76301	NMCS
1560-01-394-5310	Aircraft Skin	74A170719-2012	76301	NMCS
1620-01-116-1437	Shrink Link Assembly	74A410670-1005	76301	NMCS
1560-01-182-7972	Poppet Valve	32400-133	04192	NMCS
5995-01-156-9063	Radio Frequency Cable	1538-8215-55	11556	NMCS
5985-01-126-2949	Antenna	3682-8000	11556	PMCS
1660-01-158-1588	Fuel Heat Exchange	13451-000	12536	NMCS
6620-01-124-0947	Pressure Transmitter	3255-10303	99564	NMCS
4730-01-240-9262	Landing Gear Swivel	AE84722G	00624	NMCS
4810-01-223-8040	Solenoid Valve	234165-5	79318	NMCS
4020-01-388-5789	Fiber Rope Assembly	261120	09205	PMCS
5920-00-881-6584	Extractor Fuseholder	FHL17G2	12909	NMCS
6150-00-106-7617	Cable Assembly	178AS420	30003	NMCS
5306-01-211-5936	Tee Head Bolt	NK1005254-10	26622	NMCS
5998-01-203-2069	Circuit Card Assembly	A3-07-0096	22887	NMCS
5895-01-193-5312	Receiver Control	A3-07-0120	18560	NMCS
3010-01-151-0842	Gearcase-motor	B50-20	31882	NMCS
5995-01-204-5532	Cable Assembly	5819898G1	94117	PMCS
6695-01-136-4350	Motional Transducer	SM220-K142-3	12400	NMCS
1560-01-172-9646	Fluid Passage Bolt	74A230682-1005	76301	NMCS
4810-01-368-9652	Solenoid Valve	100271000A	76301	PMCS
5315-01-126-3827	Hollow Pin	74A450638-2001	76301	NMCS
6140-01-131-8104	Storage Battery	D8565/4-1	81349	NMCS

Table 5. Annual Demand

National Stock Number (NSN)	Unit Price	Annual Demand	National Stock Number (NSN)	Unit Price	Annual Demand
5945-01-138-5529	$2,027.22	11	1660-01-158-1588	$5,475.53	15
6685-01-123-5112	$5,285.25	11	6620-01-124-0947	$2,302.02	13
6620-01-151-0620	$2,440.35	39	4730-01-240-9262	$4,806.27	17
5930-01-115-7338	$1,460.41	15	4810-01-223-8040	$1,127.51	64
5310-01-132-3395	$92.64	12	4020-01-388-5789	$23.36	394
5315-01-138-0797	$628.71	9	5920-00-881-6584	$8.05	42
3120-01-121-1798	$153.84	14	6150-00-106-7617	$583.37	44
1560-01-407-1861	$15.68	20	5306-01-211-5936	$25.10	30
3040-01-125-8207	$1,927.81	16	5998-01-203-2069	$87.99	32
1680-01-140-3889	$154.77	12	5895-01-193-5312	$133.97	28
1560-01-166-3331	$1,218.92	9	3010-01-151-0842	$1,270.79	13
5310-01-168-4489	$2.27	45	5995-01-204-5532	$441.25	23
1560-01-394-5310	$577.25	17	6695-01-136-4350	$574.94	21
1620-01-116-1437	$3,322.20	14	1560-01-172-9646	$104.24	48
1560-01-182-7972	$1,014.20	9	4810-01-368-9652	$1,197.86	14
5995-01-156-9063	$345.58	13	5315-01-126-3827	$134.83	31
5985-01-126-2949	$1,050.90	21	6140-01-131-8104	$553.21	103

D. VARIABLE COSTS UNDER NON-JIT ENVIRONMENT

As previously noted, NAS Lemoore Aviation Support Division has two major roles in this simulation. Acting as Inventory Control Point (ICP), NAS Lemoore will manage the thirty-four items listed and bears the cost related to the procurement of replenishing stock levels or ordering cost. The consumable items in this study are currently managed by the Defense Logistics Agency. Therefore, the study utilized the Defense Logistics Agency ordering cost [Ref. 22] as an approximation of the NAS Lemoore Aviation Support Division ordering cost. These figures are depicted in Table 6 and are fundamental in determining the optimal order quantity in the model that is presented in the next chapter. In constructing this model the author relies on the following:

Table 6. Holding and Ordering Costs

National Stock Number (NSN)	Unit Price	Holding Cost/unit Per year	Ordering Cost
5945-01-138-5529	$2,027.22	$466.26	$160.15
6685-01-123-5112	$5,285.25	$1,215.61	$417.53
6620-01-151-0620	$2,440.35	$561.28	$192.79
5930-01-115-7338	$1,460.41	$335.89	$115.37
5310-01-132-3395	$92.64	$21.31	$7.32
5315-01-138-0797	$628.71	$144.60	$49.67
3120-01-121-1798	$153.84	$35.38	$12.15
1560-01-407-1861	$15.68	$3.61	$1.24
3040-01-125-8207	$1,927.81	$443.40	$152.30
1680-01-140-3889	$154.77	$35.60	$12.23
1560-01-166-3331	$1,218.92	$280.35	$96.29
5310-01-168-4489	$2.27	$0.52	$0.18
1560-01-394-5310	$577.25	$132.77	$45.60
1620-01-116-1437	$3,322.20	$764.11	$262.45
1560-01-182-7972	$1,014.20	$233.27	$80.12
5995-01-156-9063	$345.58	$79.48	$27.30
5985-01-126-2949	$1,050.90	$241.71	$83.02
1660-01-158-1588	$5,475.53	$1,259.37	$432.57
6620-01-124-0947	$2,302.02	$529.46	$181.86
4730-01-240-9262	$4,806.27	$1,105.44	$379.70
4810-01-223-8040	$1,127.51	$259.33	$89.07
4020-01-388-5789	$23.36	$5.37	$1.85
5920-00-881-6584	$8.05	$1.85	$0.64
6150-00-106-7617	$583.37	$134.18	$46.09
5306-01-211-5936	$25.10	$5.77	$1.98
5998-01-203-2069	$87.99	$20.24	$6.95
5895-01-193-5312	$133.97	$30.81	$10.58
3010-01-151-0842	$1,270.79	$292.28	$100.39
5995-01-204-5532	$441.25	$101.49	$34.86
6695-01-136-4350	$574.94	$132.24	$45.42
1560-01-172-9646	$104.24	$23.98	$8.23
4810-01-368-9652	$1,197.86	$275.51	$94.63
5315-01-126-3827	$134.83	$31.01	$10.65
6140-01-131-8104	$553.21	$127.24	$43.70

> To help solve the problems of inventory, it is necessary to build mathematical models which describe the inventory situation. Since it is never possible to represent the real world with total accuracy, approximations and simplifications must be made during the model-building process. These deviations from reality are necessary for the practical reason that extremely accurate models can be so expensive that their final benefit does not justify the cost of building, maintaining, and running the model. [Ref. 5]

Table 6 also shows the annual holding costs for NAS Lemoore when acting as a stock point. This figure was calculated using the standard 23 percent over the unit price as mentioned in Section B of the previous chapter. This same standard percentage is utilized by the General Accounting Office in its investigation [Ref. 23].

This research will not consider stockout costs due to the difficulty in obtaining dollar values for the costs of a shortage in the military environment[Ref. 5].

E. COSTS OF MANAGING INVENTORIES UNDER JIT

JIT literature highlights several assumptions when used for inventory management. This presents some limitations in constructing a model to support further research into the trade-off analysis of this study.

Inventory managers in a JIT environment should narrow their overall suppliers down to a small number. They should build long-term relationships with the remaining suppliers to support long-term contracts. As a result of this narrowing the burden to place an order will be minimized. This is because a phone call should be enough to let the supplier know the buyer's needs. Furthermore, the use of Electronic Data Interchange (EDI)[4] has evolved dramatically over the years, reducing or eliminating purchasing administrative costs. In this context and applying the same concept developed by Yano [Ref. 25] in his model, this study will assume that the order processing or transaction cost per shipment is negligible.

Similarly, there are no holding costs because the material is delivered by the supplier when needed by the customer. This avoids the cost of carrying inventories. In that sense, the holding costs that the Navy normally would pay are hidden in the unit price charged by the manufacturer or supplier. This is because the supplier sustain the cost of carrying the material and providing it when needed by the Navy. Therefore, this cost is not a direct cost that needs to be accounted for in this study.

The only driver left is the cost of transportation. Transportation cost is highly dependent upon the mode of transportation and the details of the contract. In this study, it is assumed that air transportation is the appropriate means of transportation for Just-In-Time deliveries. This is because the characteristics of the material involved in this research requires an expedited, fast, and dependable way to move things from Point A to Point B.

Table 7 highlights the regular cost of shipping using either the standard overnight or 2-day service. Those figures

---

4 Electronic Data Interchange is the inter-company, computer-to-computer communication of data which allows the receiver to perform a standard business transaction with data that is in a standard data format [Ref. 24: p. 10-12].

Table 7. Regular Cost of Shipping

National Stock Number (NSN)	Unit Price	Weight (Pounds)	Shipping Costs	
			Standard Overnight	2-Day Service
5945-01-138-5529	$2,027.22	1.00	$29.50	$19.75
6685-01-123-5112	$5,285.25	1.00	$45.50	$35.75
6620-01-151-0620	$2,440.35	1.75	$33.75	$22.75
5930-01-115-7338	$1,460.41	1.00	$25.00	$15.25
5310-01-132-3395	$92.64	1.00	$13.75	$7.00
5315-01-138-0797	$628.71	1.20	$22.00	$12.50
3120-01-121-1798	$153.84	1.14	$21.00	$11.50
1560-01-407-1861	$15.68	1.00	$13.75	$7.00
3040-01-125-8207	$1,927.81	1.00	$28.50	$19.00
1680-01-140-3889	$154.77	1.00	$16.25	$9.50
1560-01-166-3331	$1,218.92	2.93	$22.25	$14.25
5310-01-168-4489	$2.27	1.00	$18.50	$9.00
1560-01-394-5310	$577.25	1.00	$21.50	$12.00
1620-01-116-1437	$3,322.20	3.04	$39.75	$28.25
1560-01-182-7972	$1,014.20	1.65	$20.25	$12.75
5995-01-156-9063	$345.58	1.00	$21.50	$11.75
5985-01-126-2949	$1,050.90	1.00	$24.50	$14.75
1660-01-158-1588	$5,475.53	6.20	$57.00	$44.50
6620-01-124-0947	$2,302.02	1.57	$26.75	$19.25
4730-01-240-9262	$4,806.27	1.00	$43.50	$33.75
4810-01-223-8040	$1,127.51	2.60	$21.75	$13.75
4020-01-388-5789	$23.36	1.00	$13.75	$7.00
5920-00-881-6584	$8.05	1.00	$19.00	$9.25
6150-00-106-7617	$583.37	1.50	$24.25	$13.25
5306-01-211-5936	$25.10	1.00	$18.00	$8.25
5998-01-203-2069	$87.99	13.00	$42.25	$26.25
5895-01-193-5312	$133.97	6.00	$32.00	$19.50
3010-01-151-0842	$1,270.79	1.02	$21.50	$13.75
5995-01-204-5532	$441.25	1.25	$21.50	$11.75
6695-01-136-4350	$574.94	1.00	$22.00	$12.25
1560-01-172-9646	$104.24	1.00	$21.00	$11.50
4810-01-368-9652	$1,197.86	1.00	$24.50	$15.00
5315-01-126-3827	$134.83	1.00	$21.00	$11.50
6140-01-131-8104	$553.21	26.30	$65.25	$48.00

were gathered from a shipping rate software developed by Federal Express Corporation [Ref. 26]. The major input parameters were: origin (supplier stock point), destination (NAS Lemoore), unit price, and weight. From the table it can be seen that 55 percent of the items are listed with weights of one pound. This figure was listed to meet the minimum constraint imposed by the transportation company in its pricing policy. However, all items mentioned weigh much less than one pound.

F. CHAPTER SUMMARY

This chapter has provided the list of selected items which were analyzed in this study. Those items were selected due to their influence in FA-18 readiness. It also provides quantitative data related to the demand at Naval Air Station Lemoore, the price to ship different items from the supplier to NAS Lemoore, and holding and ordering costs as if the selected items were managed by Lemoore.

The next chapter presents the results of using a mathematical model to analyze the cost behavior under the two Inventory Management Techniques that are the focus of this study.

IV. ANALYSIS AND RESULTS

A. CHAPTER OVERVIEW

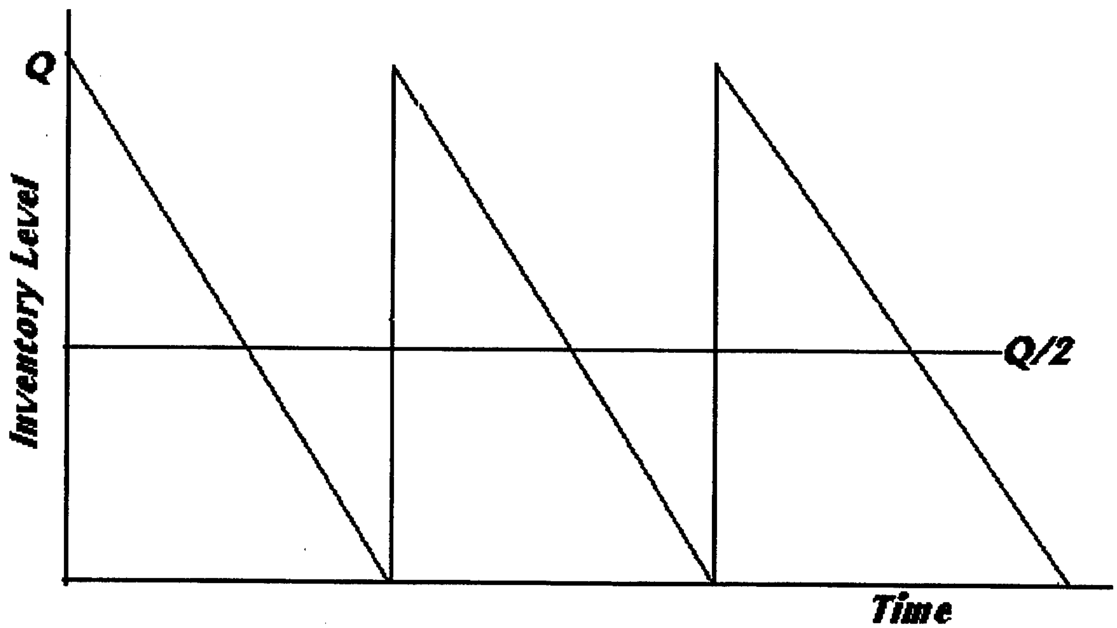
Chapter III presented the data and its sources. This information is essential in building a baseline to further assess and draw conclusions for the study.

This chapter will further develop the analysis by introducing the Economic Order Model, presenting holding cost and transportation cost curve behavior and presenting a break-even model using holding and transportation costs. The model will be illustrated and analyzed using graphics, tables, and mathematical equations.

B. THE ECONOMIC ORDER QUANTITY MODEL

The two fundamental questions faced by any traditional inventory system are when should an order be placed and what quantity should be ordered [Ref. 27]. To answer the second question, the US Navy Supply System and the Army Inventory Management System use some form of the Economic Order Quantity (EOQ) to determine the size of the reorder quantity [Ref. 5, 28]. This particular quantity (*Q*) is utilized to bring the inventory level to its maximum position. After that units are consumed at a constant rate. This classical inventory behavior is presented in Figure 2.

The quantity (*Q*) is expected to be a level which minimizes the total inventory cost per year. This cost is represented by the following equation:



Q= Lot size
Q/2 =Average Inventory

Figure 2. Classical Inventory Behavior

Total Annual Cost = Purchase Cost + Order Cost + Holding Cost

$$TC(Q) = PD + \frac{CD}{Q} + \frac{HQ}{2} \quad , \qquad (1)$$

where:

D = Annual Demand in Units,

P = Purchase Cost of an Item,

C = Ordering Cost Per Order,

H=PF = Holding Cost per unit per Year,

Q = Lot size or Order Quantity in Units,

F = Annual Holding Cost as a fraction of units Cost. [Ref. 29]

From the equation above it is apparent that PD is constant which is independent of the parameter Q. Therefore, the minimization process occurs when there is a trade-off situation between the variable cost for ordering and holding inventories. This is an agreement with the following General

Accounting Office Publications for the management of secondary items:

> Ordering and holding cost values influence the quantity of a purchase. As order quantities decline, the number of purchases and, accordingly, ordering cost should increase. As order quantities increase, the number of purchases and the procurement work load should decrease. These things are offset by a higher investment in inventory, which increases holding cost, and a reduction in the ability of the supply system to adjust to changes in future demand, which increases the likelihood of having inventory not supported by requirements. [Ref. 23]

Figure 3 summarizes the issues discussed above regarding the classical EOQ model, which is supported, among others, by the following assumptions:

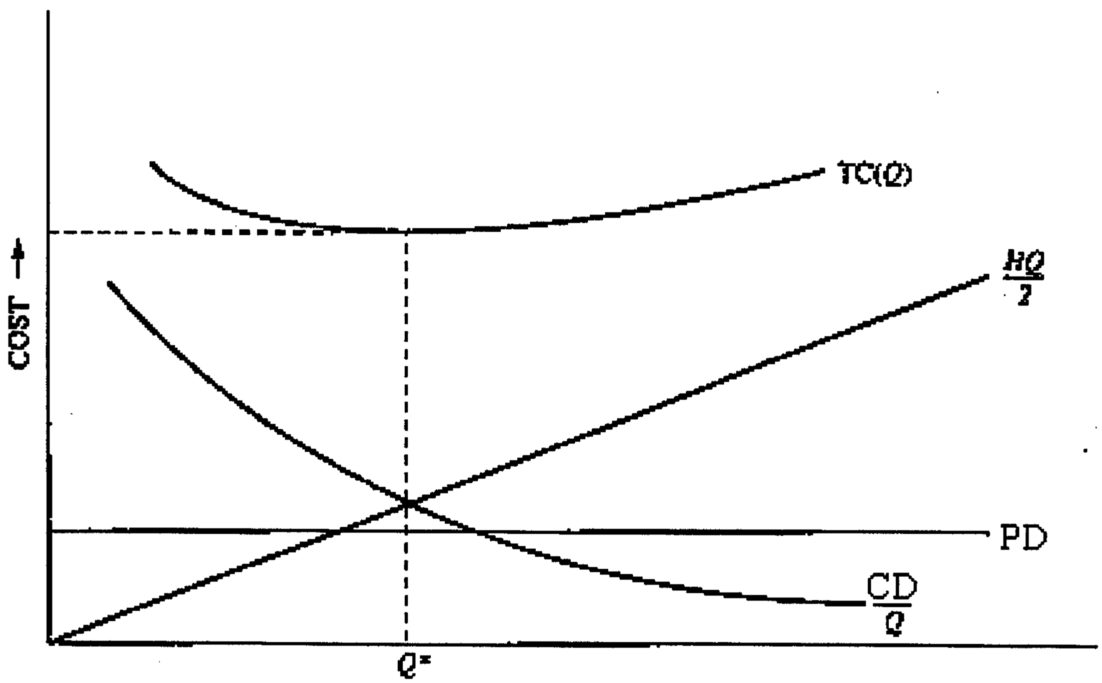


Figure 3. Classical EOQ Model

- The demand rate is known and constant.

- The entire lot size is added to inventory at the same time.
- No stockout are permitted.
- The cost structure is fixed; order costs are the same regardless of lot size, holding cost is a linear function based on average inventory, and unit purchase cost is constant.
- There is sufficient space, capacity, and capital to procure the desired quantity.
- The item is a single product; it does not interact with any other inventory items (there are no joint orders) [Ref. 29].

The point Q^*, the minimum total annual cost, is mathematically represented by the equation:

$$Q^* = \sqrt{\frac{2 \times C \times D}{H}} = \sqrt{\frac{2 \times C \times D}{P \times F}} \,. \tag{2}$$

Frequently, the square root does not result in an integer. Because some products may not be issued in a fraction of one unit, in practice, the result is rounded up to the next integer. This does not invalidate the model because, as can be seen in Figure 3, the total curve is shallow near the *EOQ*. This leads to the conclusion that small variations on the resulting quantity tend to have little effect on total cost [Ref. 23]. Consequently, for a certain range of annual demand and after rounding up the result using EOQ formula, the result will be the same value for Q^* for that particular range. Table 8 depicts the respective calculations for one particular item introduced in the previous chapter.

Table 8. EOQ Calculus for Item 3120-01-1798

Annual Demand	Holding Cost/Unit Per Year	Ordering Cost	EOQ Formula	EOQ Rounding Up
13	35.3832	12.15336	2.988383306	3
14	35.3832	12.15336	3.101191917	4
15	35.3832	12.15336	3.210038602	4
16	35.3832	12.15336	3.315313612	4
17	35.3832	12.15336	3.417347051	4
18	35.3832	12.15336	3.516421106	4
19	35.3832	12.15336	3.612779251	4
20	35.3832	12.15336	3.706633302	4
21	35.3832	12.15336	3.798168895	4
22	35.3832	12.15336	3.887549804	4
23	35.3832	12.15336	3.974921383	4
24	35.3832	12.15336	4.060413344	5

As an extension of the sensitivity analysis above, the following two tables (Tables 9 and 10) highlight the deviation in the order quantity in response to some variation in the parameters of ordering cost and holding cost.

Table 9. Effects on EOQ by changing the Ordering Cost of the item 3040-01-125-8207

Ordering Cost (OC)	% Change in OC	EOQ Formula	% Change in EOQ
$106.61	30%	2.77	16.33%
$152.30	**0%**	**3.32**	**0.00%**
$197.99	30%	3.78	14.02%

Table 10. Effects on EOQ by Changing the Holding Cost of the Item 3040-01-125-8207

Holding Cost/unit Per year	% change in HC	EOQ Formula	% change in EOQ
$310.38	30%	3.96	19.52%
$443.40	**0%**	**3.32**	**0.00%**
$576.42	30%	2.91	12.29%

As shown in Tables 9 and 10, an increase in the ordering cost from $152.30 to $197.99 (about 30 percent) would increase the order quantity by 14 percent. On the other hand, a similar decrease in the ordering cost from $152.30 to $106.61 (about 30 percent) would decrease the quantity by 16 percent. Alternatively, an increase in the holding cost from $443.40 to $576.42 (about 30 percent) would decrease the order quantity by 12 percent while a decrease of 30 percent results in increasing the order quantity 19 percent.

C. THE HOLDING COST CURVE BEHAVIOR

The central theme of the previous section was to find the economic order quantity which minimizes the total annual cost. This figure is fundamental in determining the annual holding cost which is represented by the straight line $\frac{HQ}{2}$ in the EOQ model, assuming that the demand is constant at a certain level of consumption. The holding cost curve is reproduced in the Figure 4, where the independent variable is the order quantity and the optimal point is denoted by Q^*.

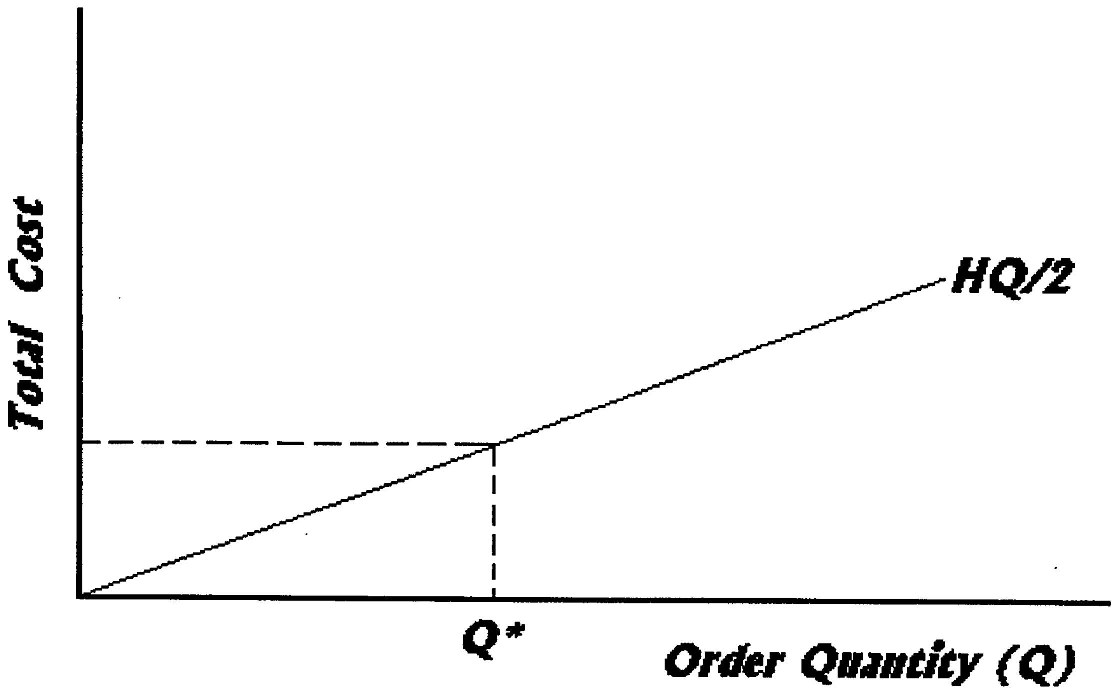


Figure 4. Holding Cost Curve

The linearity of the holding cost curve changes to a step curve if one decides to change the independent variable to annual demand and change the vertical axis to optimal holding cost. This behavior is justified by the fact that a small group of different demands, after rounding up the *EOQ* formula, will have the same Q^*. This Q^* used in the $\frac{HQ}{2}$ formula, will result in the same optimal holding cost for the referred group of demand. Table 8 has already addressed this issue, likewise Figure 5 also shows this behavior. This characteristic is going to be instrumental in this study and there will be an analysis of the optimal holding cost for the different levels of demand.

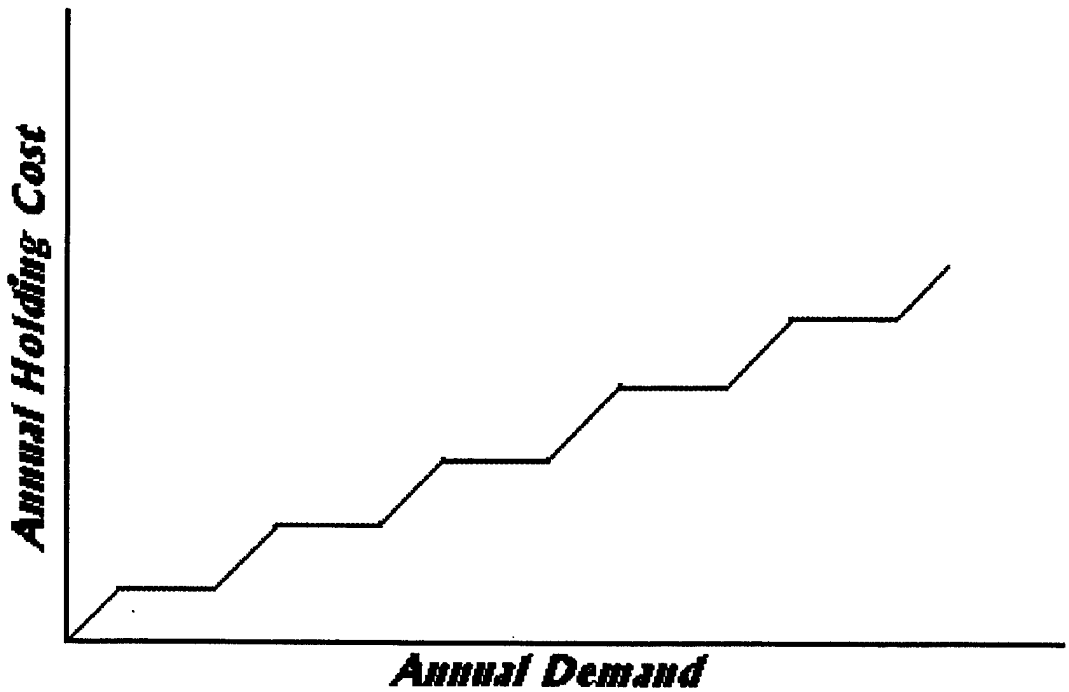


Figure 5. Annual Demand X Annual Holding Cost

D. TRANSPORTATION COST CURVE UNDER JIT ENVIRONMENT

The transportation cost is the only driver under the JIT technique that will be considered in this investigation. The transportation cost has a direct relationship with each level of annual demand. For example, if annual demand is 4 units and the shipping price per unit is $5.00, then the annual transportation cost is $20.00. Similarly, if annual demand increases to 10 units, the annual transportation cost changes to $50.00. Figure 6 illustrates this behavior.

E. THE DEMAND BREAK-EVEN POINT BASED ON HOLDING COST AND TRANSPORTATION COST

This author suggests that there is a particular point where holding and transportation costs will cross. This region defines for the inventory manager the initial evidence

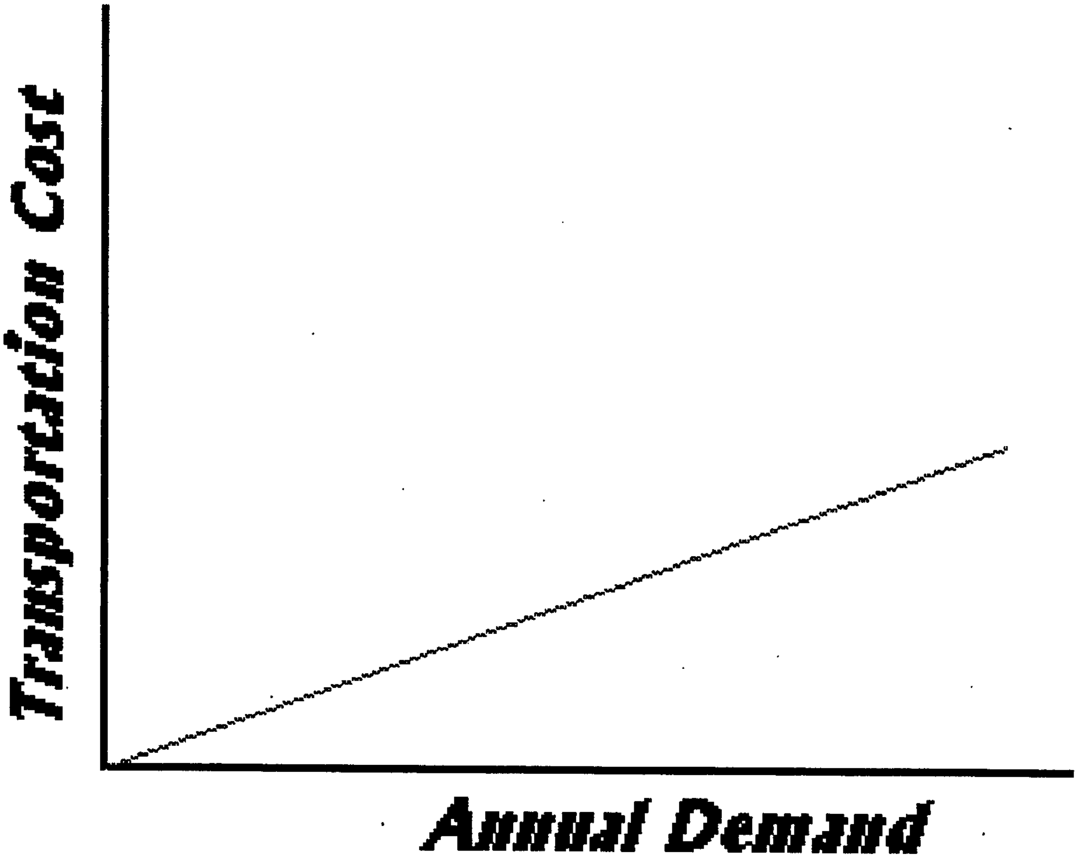


Figure 6. Annual Transportation Cost Changes

concerning which technique will yield cost savings when operating at the different levels of annual demand. Figure 7 shows this theoretical model which will be graphically and mathematically explored in the next section, using the data presented in Chapter III. An equation is developed in the Appendix to support this mathematical approach.

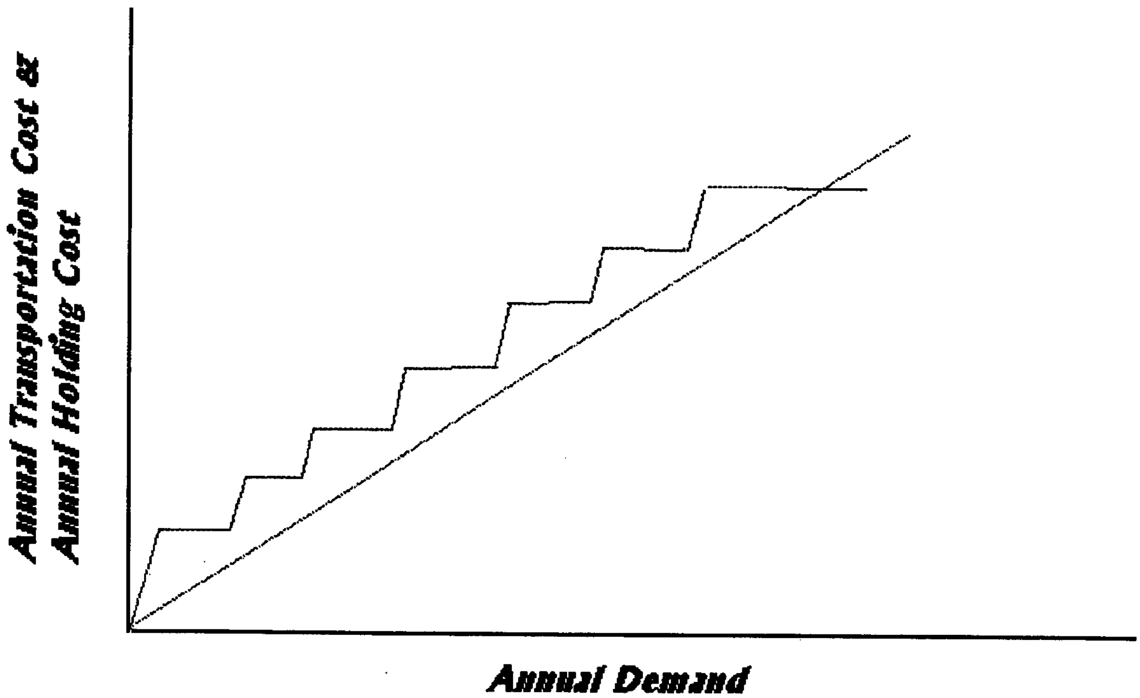


Figure 7. Theoretical Model

F. TOTAL ANNUAL HOLDING COST CALCULATIONS IN A NON-JIT ENVIRONMENT

Table 11 provides the annual holding cost for each item listed in the previous chapter, using the demand levels provided by NAS Lemoore.

Taking item 1660-01-158-1588 from Table 11, it demonstrates that the value $2,518.74 was the result of the following equation:

$$EOQ = \sqrt{\frac{2 \times C \times D}{H}} = \sqrt{\frac{2 \times 432.57 \times 15}{1{,}259.37}} = 3.21$$

Rounding up the number above to the nearest integer, the result is 4. The optimal annual holding cost is given by $\frac{HQ}{2}$, and the final result will be $\frac{1{,}259.37 \times 4}{2} = 2{,}518.74$.

Table 11. Annual Holding Cost Calculation

National Stock Number	Annual Demand	Holding Cost/unit Per Year	Ordering Cost	EOQ Formula	EOQ Rounding UP	Annual Holding Cost
5945-01-138-5529	11	$ 466.26	$ 160.15	2.75	3	$ 699.39
6685-01-123-5112	11	$ 1,215.61	$ 417.53	2.75	3	$ 1,823.41
6620-01-151-0620	39	$ 561.28	$ 192.79	5.18	6	$ 1,683.84
5930-01-115-7338	15	$ 335.89	$ 115.37	3.21	4	$ 671.79
5310-01-132-3395	12	$ 21.31	$ 7.32	2.87	3	$ 31.96
5315-01-138-0797	9	$ 144.60	$ 49.67	2.49	3	$ 216.90
3120-01-121-1798	14	$ 35.38	$ 12.15	3.10	4	$ 70.77
1560-01-407-1861	20	$ 3.61	$ 1.24	3.71	4	$ 7.21
3040-01-125-8207	16	$ 443.40	$ 152.30	3.32	4	$ 886.79
1680-01-140-3889	12	$ 35.60	$ 12.23	2.87	3	$ 53.40
1560-01-166-3331	9	$ 280.35	$ 96.29	2.49	3	$ 420.53
5310-01-168-4489	45	$ 0.52	$ 0.18	5.56	6	$ 1.57
1560-01-394-5310	17	$ 132.77	$ 45.60	3.42	4	$ 265.54
1620-01-116-1437	14	$ 764.11	$ 262.45	3.10	4	$ 1,528.21
1560-01-182-7972	9	$ 233.27	$ 80.12	2.49	3	$ 349.90
5995-01-156-9063	13	$ 79.48	$ 27.30	2.99	3	$ 119.23
5985-01-126-2949	21	$ 241.71	$ 83.02	3.80	4	$ 483.41
1660-01-158-1588	15	$ 1,259.37	$ 432.57	3.21	4	$ 2,518.74
6620-01-124-0947	13	$ 529.46	$ 181.86	2.99	3	$ 794.20
4730-01-240-9262	17	$ 1,105.44	$ 379.70	3.42	4	$ 2,210.88
4810-01-223-8040	64	$ 259.33	$ 89.07	6.63	7	$ 907.65
4020-01-388-5789	394	$ 5.37	$ 1.85	16.45	17	$ 45.67
5920-00-881-6584	42	$ 1.85	$ 0.64	5.37	6	$ 5.55
6150-00-106-7617	44	$ 134.18	$ 46.09	5.50	6	$ 402.53
5306-01-211-5936	30	$ 5.77	$ 1.98	4.54	5	$ 14.43
5998-01-203-2069	32	$ 20.24	$ 6.95	4.69	5	$ 50.59
5895-01-193-5312	28	$ 30.81	$ 10.58	4.39	5	$ 77.03
3010-01-151-0842	13	$ 292.28	$ 100.39	2.99	3	$ 438.42
5995-01-204-5532	23	$ 101.49	$ 34.86	3.97	4	$ 202.98
6695-01-136-4350	21	$ 132.24	$ 45.42	3.80	4	$ 264.47
1560-01-172-9646	48	$ 23.98	$ 8.23	5.74	6	$ 71.93
4810-01-368-9652	14	$ 275.51	$ 94.63	3.10	4	$ 551.02
5315-01-126-3827	31	$ 31.01	$ 10.65	4.61	5	$ 77.53
6140-01-131-8104	103	$ 127.24	$ 43.70	8.41	9	$ 572.57
					Total:	$ 18,520.03

The total annual holding cost to managing the selected 34 items under a traditional inventory technique is $18,520.03.

G. ANNUAL TRANSPORTATION COST UNDER JIT ENVIRONMENT

The annual transportation cost in a JIT environment is shown in Table 12. The basic calculus was done by taking the annual demand for each item and multiplying the unit shipping

Table 12. Annual Transportation Costs in a JIT Environment

National Stock Number	Annual Demand	Standard Overnight	2-Day Service	Transportation Cost Option 1	Transportation Cost Option 2
5945-01-138-5529	11	$ 29.50	$ 19.75	$ 324.50	$ 217.25
6685-01-123-5112	11	$ 45.50	$ 35.75	$ 500.50	$ 393.25
6620-01-151-0620	39	$ 33.75	$ 22.75	$ 1,316.25	$ 887.25
5930-01-115-7338	15	$ 25.00	$ 15.25	$ 375.00	$ 228.75
5310-01-132-3395	12	$ 13.75	$ 7.00	$ 165.00	$ 84.00
5315-01-138-0797	9	$ 22.00	$ 12.50	$ 198.00	$ 112.50
3120-01-121-1798	14	$ 21.00	$ 11.50	$ 294.00	$ 161.00
1560-01-407-1861	20	$ 13.75	$ 7.00	$ 275.00	$ 140.00
3040-01-125-8207	16	$ 28.50	$ 19.00	$ 456.00	$ 304.00
1680-01-140-3889	12	$ 16.25	$ 9.50	$ 195.00	$ 114.00
1560-01-166-3331	9	$ 22.25	$ 14.25	$ 200.25	$ 128.25
5310-01-168-4489	45	$ 18.50	$ 9.00	$ 832.50	$ 405.00
1560-01-394-5310	17	$ 21.50	$ 12.00	$ 365.50	$ 204.00
1620-01-116-1437	14	$ 39.75	$ 28.25	$ 556.50	$ 395.50
1560-01-182-7972	9	$ 20.25	$ 12.75	$ 182.25	$ 114.75
5995-01-156-9063	13	$ 21.50	$ 11.75	$ 279.50	$ 152.75
5985-01-126-2949	21	$ 24.50	$ 14.75	$ 514.50	$ 309.75
1660-01-158-1588	15	$ 57.00	$ 44.50	$ 855.00	$ 667.50
6620-01-124-0947	13	$ 26.75	$ 19.25	$ 347.75	$ 250.25
4730-01-240-9262	17	$ 43.50	$ 33.75	$ 739.50	$ 573.75
4810-01-223-8040	64	$ 21.75	$ 13.75	$ 1,392.00	$ 880.00
4020-01-388-5789	394	$ 13.75	$ 7.00	$ 5,417.50	$ 2,758.00
5920-00-881-6584	42	$ 19.00	$ 9.25	$ 798.00	$ 388.50
6150-00-106-7617	44	$ 24.25	$ 13.25	$ 1,067.00	$ 583.00
5306-01-211-5936	30	$ 18.00	$ 8.25	$ 540.00	$ 247.50
5998-01-203-2069	32	$ 42.25	$ 26.25	$ 1,352.00	$ 840.00
5895-01-193-5312	28	$ 32.00	$ 19.50	$ 896.00	$ 546.00
3010-01-151-0842	13	$ 21.50	$ 13.75	$ 279.50	$ 178.75
5995-01-204-5532	23	$ 21.50	$ 11.75	$ 494.50	$ 270.25
6695-01-136-4350	21	$ 22.00	$ 12.25	$ 462.00	$ 257.25
1560-01-172-9646	48	$ 21.00	$ 11.50	$ 1,008.00	$ 552.00
4810-01-368-9652	14	$ 24.50	$ 15.00	$ 343.00	$ 210.00
5315-01-126-3827	31	$ 21.00	$ 11.50	$ 651.00	$ 356.50
6140-01-131-8104	103	$ 65.25	$ 48.00	$ 6,720.75	$ 4,944.00
Total Annual Transportation Cos				$ 30,393.75	$ 18,855.25

cost for that item. The annual overnight delivery cost is recorded in Column Option 1, the 2-Day service is listed in Column Option 2. For the purpose of this examination, the study will use the overnight service cost. This is because in order for the FA-18 units maintain a state of high readiness, the fastest service option would be used. In the initial investigation for the study, these items were identified as the most likely to result in a decrease in readiness of the FA-18 aircraft.

Table 12 also shows that if the inventory manager decided to use JIT for all items being analyzed, he would end up having a total annual transportation cost of $30,393.75.

H. TEST FOR JIT ACCEPTABILITY

Table 13 lists the contrasting dollar figures between the major cost driver in each technique. The two right hand columns indicate whether JIT is the most appropriate inventory management technique.

I. GRAPHICAL AND MATHEMATICAL ANALYSIS

In fact, Table 13 shows evidences that JIT is not always the most reasonable approach. As a result, there will always be a trade-off region where inventory managers can decide which procedure is the most suitable according to the cost drivers in focus.

The next step in this investigation will be a graphical and mathematical break-even point analysis of two items picked from the initial group. These items were selected randomly. They had different recommendations in Table 13 as far as the practice of JIT in managing those items.

Table 13. Contrasting Dollar Figures for Major Cost Drivers

A	B	C	D	E	F
National Stock Number	Annual Demand	Transport. Cost Overnight	Annual Holding Cost	JIT Should be Used ?	OBS
5945-01-138-5529	11	$ 324.50	$ 699.39	YES	C<D
6685-01-123-5112	11	$ 500.50	$ 1,823.41	YES	C<D
6620-01-151-0620	39	$ 1,316.25	$ 1,683.84	YES	C<D
5930-01-115-7338	15	$ 375.00	$ 671.79	YES	C<D
5315-01-138-0797	9	$ 198.00	$ 216.90	YES	C<D
3040-01-125-8207	16	$ 456.00	$ 886.79	YES	C<D
1560-01-166-3331	9	$ 200.25	$ 420.53	YES	C<D
1620-01-116-1437	14	$ 556.50	$ 1,528.21	YES	C<D
1560-01-182-7972	9	$ 182.25	$ 349.90	YES	C<D
1660-01-158-1588	15	$ 855.00	$ 2,518.74	YES	C<D
6620-01-124-0947	13	$ 347.75	$ 794.20	YES	C<D
4730-01-240-9262	17	$ 739.50	$ 2,210.88	YES	C<D
3010-01-151-0842	13	$ 279.50	$ 438.42	YES	C<D
4810-01-368-9652	14	$ 343.00	$ 551.02	YES	C<D
5310-01-132-3395	12	$ 165.00	$ 31.96	NO	C>D
3120-01-121-1798	14	$ 294.00	$ 70.77	NO	C>D
1560-01-407-1861	20	$ 275.00	$ 7.21	NO	C>D
1680-01-140-3889	12	$ 195.00	$ 53.40	NO	C>D
5310-01-168-4489	45	$ 832.50	$ 1.57	NO	C>D
1560-01-394-5310	17	$ 365.50	$ 265.54	NO	C>D
5995-01-156-9063	13	$ 279.50	$ 119.23	NO	C>D
5985-01-126-2949	21	$ 514.50	$ 483.41	NO	C>D
4810-01-223-8040	64	$ 1,392.00	$ 907.65	NO	C>D
4020-01-388-5789	394	$ 5,417.50	$ 45.67	NO	C>D
5920-00-881-6584	42	$ 798.00	$ 5.55	NO	C>D
6150-00-106-7617	44	$ 1,067.00	$ 402.53	NO	C>D
5306-01-211-5936	30	$ 540.00	$ 14.43	NO	C>D
5998-01-203-2069	32	$ 1,352.00	$ 50.59	NO	C>D
5895-01-193-5312	28	$ 896.00	$ 77.03	NO	C>D
5995-01-204-5532	23	$ 494.50	$ 202.98	NO	C>D
6695-01-136-4350	21	$ 462.00	$ 264.47	NO	C>D
1560-01-172-9646	48	$ 1,008.00	$ 71.93	NO	C>D
5315-01-126-3827	31	$ 651.00	$ 77.53	NO	C>D
6140-01-131-8104	103	$ 6,720.75	$ 572.57	NO	C>D

Table 14 reproduces the different annual holding and transportation costs for distinct levels of demand throughout the same year for item 1660-01-158-1588. This item was selected to be under the JIT umbrella.

Table 14. Break-Even Point for Item 1660-01-158-1588

Initial data from Chapter Three				
Annual Demand	**Holding Cost/unit Per Year**	**Ordering Cost**	**Unit Price**	**Overnight Shipping Per Unit**
15	$ 1,259.37	$ 432.57	$ 5,475.53	$ 57.00
Data Break Down				
Levels of Demand	**EOQ Formula**	**EOQ Rounding up**	**Annual Holding Cost**	**Annual Shipping Cost**
1	0.83	1	$ 629.69	$ 57.00
5	1.85	2	$ 1,259.37	$ 285.00
9	2.49	3	$ 1,889.06	$ 513.00
13	2.99	3	$ 1,889.06	$ 741.00
17	3.42	4	$ 2,518.74	$ 969.00
21	3.80	4	$ 2,518.74	$ 1,197.00
25	4.14	5	$ 3,148.43	$ 1,425.00
29	4.46	5	$ 3,148.43	$ 1,653.00
33	4.76	5	$ 3,148.43	$ 1,881.00
37	5.04	6	$ 3,778.12	$ 2,109.00
41	5.31	6	$ 3,778.12	$ 2,337.00
45	5.56	6	$ 3,778.12	$ 2,565.00
49	5.80	6	$ 3,778.12	$ 2,793.00
53	6.03	7	$ 4,407.80	$ 3,021.00
57	6.26	7	$ 4,407.80	$ 3,249.00
61	6.47	7	$ 4,407.80	$ 3,477.00
65	6.68	7	$ 4,407.80	$ 3,705.00
69	6.88	7	$ 4,407.80	$ 3,933.00
73	7.08	8	$ 5,037.49	$ 4,161.00
77	7.27	8	$ 5,037.49	$ 4,389.00
81	7.46	8	$ 5,037.49	$ 4,617.00
85	7.64	8	$ 5,037.49	$ 4,845.00
89	7.82	8	$ 5,037.49	$ 5,073.00
93	7.99	8	$ 5,037.49	$ 5,301.00

Figure 8 illustrates the behavior manifested in the prior table where the break-even point occurs when the annual demand (*D*) is near 88 units.

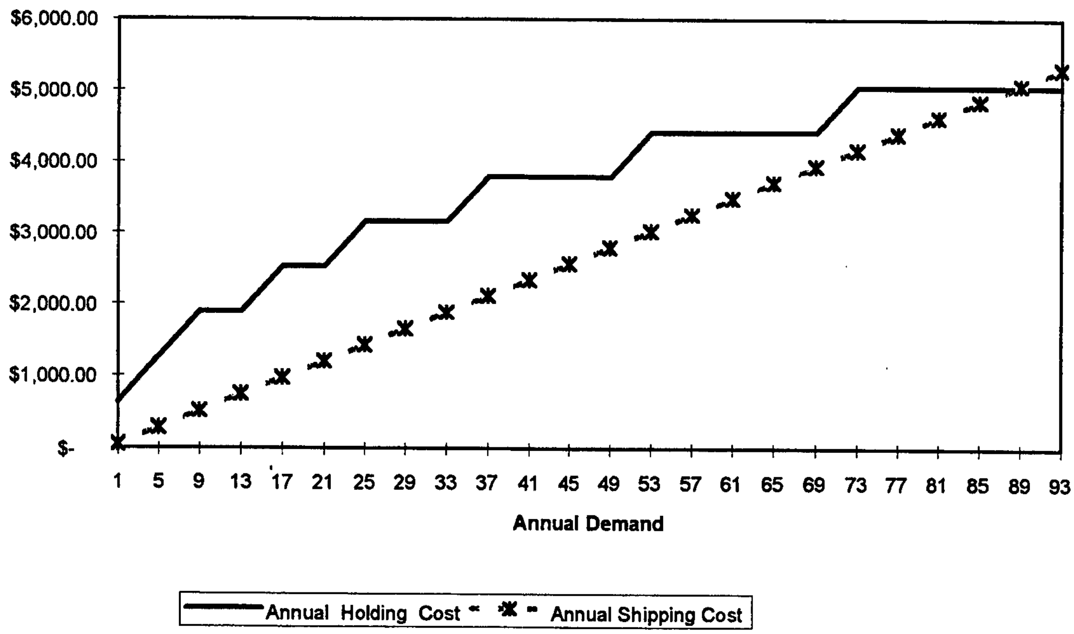


Figure 8. Break-Even Point Chart for Item 1660-01-158-1588

Mathematically, a reliable approximation is achieved through the use of the Equation (5) listed in the Appendix. The break-even point graphically and mathematically is not exactly the same due to the successive approximation built in the graphical approach. However, the numerical method is also a reliable tool in the decision process.

$$D = \frac{CH}{2 \times S^2}$$

$$D = \frac{432.57 \times 1{,}259.37}{2 \times 57^2}$$

$$D = 83.84$$

$$D \cong 84$$

Introducing a similar investigation for item 6150-00-106-7617 which was not recommended under the JIT methodology, Table 15 and Figure 9 show the graphical procedure for this item. The math calculation according to the Appendix is:

Table 15. Break-Even Point for Item 6150-00-106-7617

Initial data from Chapter Three				
Annual Demand	**Holding Cost/unit Per Year**	**Ordering Cost**	**Unit Price**	**Overnight Shipping Cost/Unit**
44	$ 134.18	$ 46.09	$ 583.37	$ 24.25
Data break down				
Levels of Demand	**EOQ Formula**	**EOQ Rounding up**	**Annual Holding Cost**	**Annual Shipping Cost**
1	0.83	1	$ 67.09	$ 24.25
3	1.44	2	$ 134.18	$ 72.75
6	2.03	3	$ 201.26	$ 145.50
9	2.49	3	$ 201.26	$ 218.25
12	2.87	3	$ 201.26	$ 291.00
15	3.21	4	$ 268.35	$ 363.75
18	3.52	4	$ 268.35	$ 436.50
21	3.80	4	$ 268.35	$ 509.25
24	4.06	5	$ 335.44	$ 582.00
27	4.31	5	$ 335.44	$ 654.75
30	4.54	5	$ 335.44	$ 727.50
33	4.76	5	$ 335.44	$ 800.25
36	4.97	5	$ 335.44	$ 873.00
39	5.18	6	$ 402.53	$ 945.75
42	5.37	6	$ 402.53	$ 1,018.50
45	5.56	6	$ 402.53	$ 1,091.25
48	5.74	6	$ 402.53	$ 1,164.00
51	5.92	6	$ 402.53	$ 1,236.75
54	6.09	7	$ 469.61	$ 1,309.50

$$D = \frac{CH}{2 \times S^2}$$

$$D = \frac{46.09 \times 134.18}{2 \times 24.25^2}$$

$$D = 5.2582$$

$$D \cong 6$$

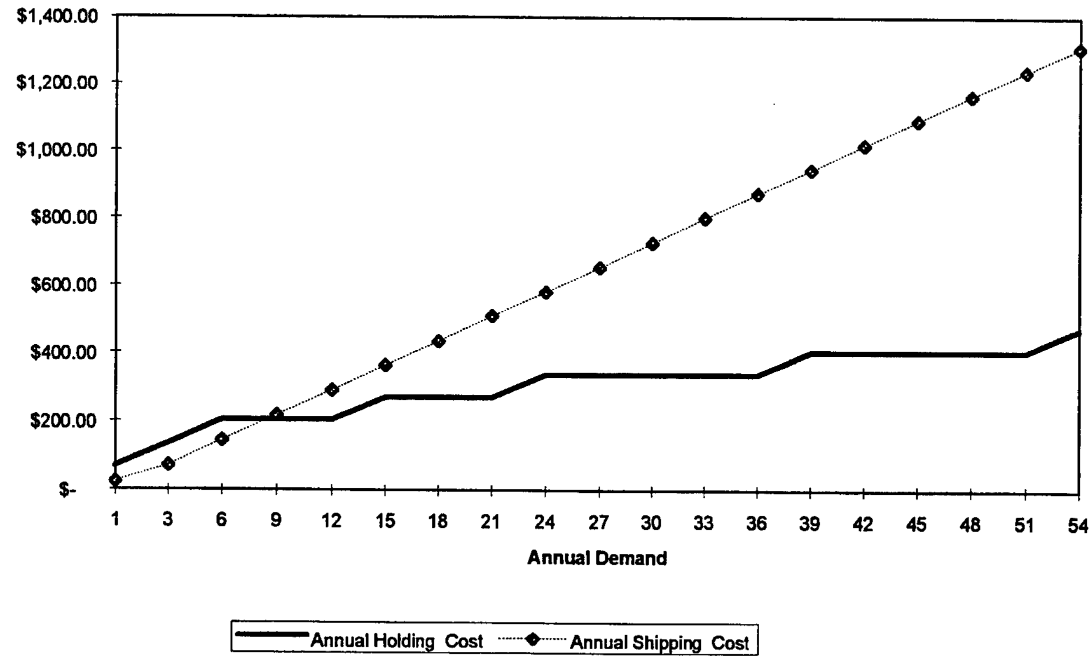


Figure 9. Break-Even Point Chart for Item 6150-00-106-7617

J. BREAK-EVEN POINT FOR ALL HEAVY HITTERS

Table 16 shows the demand break-even point for all items based on the method presented in the Appendix.

The majority of items which have been proposed for JIT management are materials with high unit prices, low demand, and very low weight. These characteristics lead to high inventory carrying costs and low shipping costs. These factors endorse just-in-time methodology as the primary inventory management technique. On the other hand, items with low value, high demand, and high weight should have inventory carrying cost figures much less than their shipping costs: therefore, the traditional methodology is more cost beneficial.

Table 16. Demand Break-Even Point for The Heavy Hitters

A	B	C	D	E	F	G	H
National Stock Number	Annual Demand	Transport. Cost Overnight	Annual Holding Cost	Demand Break-Even Point	JIT Should be Used	Weight in Pounds	Unit Price
5945-01-138-5529	11	$ 324.50	$ 699.39	43	YES	1.00	$ 2,027.22
6685-01-123-5112	11	$ 500.50	$ 1,823.41	123	YES	1.00	$ 5,285.25
6620-01-151-0620	39	$ 1,316.25	$ 1,683.84	48	YES	1.75	$ 2,440.35
5930-01-115-7338	15	$ 375.00	$ 671.79	32	YES	1.00	$ 1,460.41
5315-01-138-0797	9	$ 198.00	$ 216.90	8	YES	1.20	$ 628.71
3040-01-125-8207	16	$ 456.00	$ 886.79	42	YES	1.00	$ 1,927.81
1560-01-166-3331	9	$ 200.25	$ 420.53	28	YES	2.93	$ 1,218.92
1620-01-116-1437	14	$ 556.50	$ 1,528.21	64	YES	3.04	$ 3,322.20
1560-01-182-7972	9	$ 182.25	$ 349.90	23	YES	1.65	$ 1,014.20
1660-01-158-1588	15	$ 855.00	$ 2,518.74	84	YES	6.20	$ 5,475.53
6620-01-124-0947	13	$ 347.75	$ 794.20	68	YES	1.57	$ 2,302.02
4730-01-240-9262	17	$ 739.50	$ 2,210.88	111	YES	1.00	$ 4,806.27
3010-01-151-0842	13	$ 279.50	$ 438.42	32	YES	1.02	$ 1,270.79
4810-01-368-9652	14	$ 343.00	$ 551.02	22	YES	1.00	$ 1,197.86
5310-01-132-3395	12	$ 165.00	$ 31.96	1	NO	1.00	$ 92.64
3120-01-121-1798	14	$ 294.00	$ 70.77	1	NO	1.14	$ 153.84
1560-01-407-1861	20	$ 275.00	$ 7.21	1	NO	1.00	$ 15.68
1680-01-140-3889	12	$ 195.00	$ 53.40	1	NO	1.00	$ 154.77
5310-01-168-4489	45	$ 832.50	$ 1.57	1	NO	1.00	$ 2.27
1560-01-394-5310	17	$ 365.50	$ 265.54	7	NO	1.00	$ 577.25
5995-01-156-9063	13	$ 279.50	$ 119.23	3	NO	1.00	$ 345.58
5985-01-126-2949	21	$ 514.50	$ 483.41	17	NO	1.00	$ 1,050.90
4810-01-223-8040	64	$ 1,392.00	$ 907.65	25	NO	2.60	$ 1,127.51
4020-01-388-5789	394	$ 5,417.50	$ 45.67	1	NO	1.00	$ 23.36
5920-00-881-6584	42	$ 798.00	$ 5.55	1	NO	1.00	$ 8.05
6150-00-106-7617	44	$ 1,067.00	$ 402.53	6	NO	1.50	$ 583.37
5306-01-211-5936	30	$ 540.00	$ 14.43	1	NO	1.00	$ 25.10
5998-01-203-2069	32	$ 1,352.00	$ 50.59	1	NO	13.00	$ 87.99
5895-01-193-5312	28	$ 896.00	$ 77.03	1	NO	6.00	$ 133.97
5995-01-204-5532	23	$ 494.50	$ 202.98	4	NO	1.25	$ 441.25
6695-01-136-4350	21	$ 462.00	$ 264.47	7	NO	1.00	$ 574.94
1560-01-172-9646	48	$ 1,008.00	$ 71.93	1	NO	1.00	$ 104.24
5315-01-126-3827	31	$ 651.00	$ 77.53	1	NO	1.00	$ 134.83
6140-01-131-8104	103	$ 6,720.75	$ 572.57	1	NO	26.30	$ 553.21

K. CHAPTER SUMMARY

This chapter has contributed significantly to the core analysis of this research by showing the contrast between the two major cost drivers in the JIT and non-JIT techniques. The results indicate that despite all advantages listed in the first two chapters JIT is not always an appropriate approach. A careful inventory manager should break down the firm's cost structure and carry out a deep analysis before jumping into

JIT just because a common axiom says that the additional transportation cost is more than offset by the reduction in carrying costs. In the next chapter the study will add supplementary findings and present some suggestions for the professionals in the inventory control field.

V. CONCLUSIONS AND RECOMMENDATIONS

A. INTRODUCTION

The previous chapters have developed a trade-off assessment between JIT and non-JIT techniques, using NAS Lemoore as a hypothetical Inventory Control Point and Stock Point for a selected group of items. This chapter presents conclusions and recommendations in order to contribute to a better understanding of this research.

B. CONCLUSIONS AND RECOMMENDATIONS

1. When JIT is judged the most appropriate technique for a particular set of items, after a thorough cost analysis, JIT inventory management techniques result in cost savings and add value to the final product.

A cost analysis is advisable as the first approach in determining if JIT is feasible in a particular scenario. The analysis must consider the several variables under which the firm is operating.

Once a positive answer is achieved from analysis, the benefits acquired from JIT use can be enormous. Chapter II addressed the issue of eliminating waste and, more specifically, showed the benefits of implementing JIT including:

- Lower Costs of Holding Inventory
- Lower Capital Investment
- Quality Improvements

- Administrative Efficiency Gains

- Lower Administrative Costs

*** When the cost analysis indicates dollar savings under a JIT environment, such techniques should be definitely adopted.**

The JIT methodology may bring significant savings for a firm's inventory control operations. Therefore, it is recommended that this technique should be considered along with the other inventory management alternatives available.

2. JIT is not always the minimum cost approach when considering a wide range of items.

Taking as an example the list of items managed by NAS Lemoore in this simulation, Table 11 shows that the traditional inventory management method would incur a total annual holding cost of $ 18,520.03 for the 34 items examined. In contrast, Table 12 shows that the transportation costs for the same group of items being managed under JIT perspective, using standard overnight service, would result in a total annual transportation cost of $30,393.75. These figures indicate that a further analysis should be conducted in order to decide which technique is the more appropriate.

*** The cost elements under each technique should be delineated as the first step in the decision making process.**

In approaching the decision about which method should be utilized by a firm, there should be a calculation and explanation of the associated Annual Holding Costs for Non-JIT and the respective transportation costs for the JIT environment. These two figures will be the basis for the inventory manager's decision to use JIT.

3. An analysis item by item may lead to a different diagnosis than an analysis performed for the entire group of items being managed.

For example, Table 13 shows that only 14 items were selected for JIT out of the initial sample of 34 when comparing the major drivers of the JIT techniques.

This 41% acceptance rate for JIT was the result of breaking down the entire group and analyzing the two major drivers for each of the individual items.

Each item has different parameters that influence the holding cost and transportation cost calculations as noted throughout this research. For example, the majority of those items elected for JIT shows the profile of:

- Low demand (less than 20 units per year)
- Low weight(less than one pound)
- High price (over $1,000.00 per unit)

In contrast, the items rejected for JIT:

- High transportation cost
- Low holding cost

*** A comparison between carrying costs and transportation costs should be performed on an individual item basis.**

Only an item by item analysis can lead to effective cost savings, by avoiding generalization.

4. A graphical and mathematical break-even analysis is an excellent tool in assuring the appropriateness decision between the two techniques.

Section I of the previous chapter presented the discussion of the graphical and the mathematical analysis for item 1660-01-158-1588. This particular item shows an annual demand of 15 units at NAS Lemoore. The graphical and mathematical analysis show that the break-even point will occur when the annual demand is over 80 units. Figure 9, in particular, shows that the crossing point occurs all the way to the right of the normal annual demand which is 15 units. This remarkable result indicates that JIT is the more appropriate technique to manage this particular item. As an extension of this behavior for item 1660-01-158-1588, one might check the numbers in Column B and E shown in Table 16. This shows that the overwhelming majority of items with indications for JIT had the break-even point all the way to the far right of where the normal annual demand occurs. This reaffirms the indications for this kind of inventory guidance.

In contrast, Table 15 and Figure 9 show that item 6150-00-106-7617, that was rejected for JIT management, has a demand break-even point all the way to the left of the normal annual demand. Annual demand is 44, signaling that JIT is not a wise approach. Likewise, Table 16 highlights that all items rejected for JIT in this simulation had a break-even point far below the normal annual demand. This substantiates the rejection of JIT as a course of action.

* **The trade-off analysis using the break-even point between the major cost driver for each technique should be used as a filter to take advantage of the full benefits associated with JIT. Inventory managers should develop the costs associated with each technique and develop a trade-off methodology, on an individual item basis. This should determine the approach that is the most suitable for each item. This is done in the context of the firm's operation, according to the company's cost structure and the demand level for each item.**

C. SUMMARY

The first two chapters of this research presented the advantages and benefits of using JIT in managing inventories. Chapter III and IV developed a simulation with the purpose of showing that JIT can be effective in producing cost savings, but of course, this is not always the case. The inventory manager should investigate the cost associated with each technique. This research showed that, out of the 34 item studied, only 14 were selected for JIT methodology. In summary, NAS Lemoore would have to adopt a mix of two techniques to get the full benefits of the potential cost savings.

APPENDIX

The Math calculus for the break-even point may be defined as follows:

$$\text{Holding Cost} = \text{Transportation Cost}$$

$$\frac{HQ}{2} = D \times S \qquad , \qquad \textbf{(3)}$$

were:

H= Holding cost per unit per year,

Q= Economic Order Size,

D= Annual demand

S= Unit shipping cost.

$Q = \sqrt{\frac{2 \times C \times D}{H}}$, changing Q in Equation (3):

$$H \times \sqrt{\frac{2 \times D \times C}{H}} \div 2 = D \times S,$$

$$H \times \sqrt{\frac{2 \times D \times C}{H}} = 2 \times D \times S,$$

$$\sqrt{\frac{2 \times D \times C}{H}} = \frac{2 \times D \times S}{H},$$

$$\left(\sqrt{\frac{2 \times D \times C}{H}}\right)^2 = \left(\frac{2 \times D \times S}{H}\right)^2,$$

$$\frac{2 \times D \times C}{H} = \frac{4 \times D^2 \times S^2}{H^2},$$

$$4 \times S^2 \times H \times D^2 = 2 \times C \times H^2 \times D,$$

$$4 \times S^2 \times H \times D^2 - 2 \times C \times H^2 \times D = 0.$$

Using the formula for the quadratic equation, the zeros of any quadratic equation are expressed by:

$$X = \frac{\left(-b \pm \sqrt{b^2 - 4ac}\right)}{2a}, \qquad \textbf{(4)}$$

adjusting the coefficients in (4) for: $b=-2CH^2, a=4S^2H, c=0$, the result will be:

$$D=\frac{2\times CH^2\pm\sqrt{\left(-2\times C\times H^2\right)^2}}{2\times\left(4\times S^2\times H\right)},$$

$$D=\frac{2\times C\times H^2\pm 2\times C\times H^2}{8\times S^2\times H},$$

$$D_1=\frac{2\times C\times H^2-2\times C\times H^2}{8\times S^2\times H}=0 \text{ (this point will be disregarded),}$$

$$D_2=\frac{2\times C\times H^2+2\times C\times H^2}{8\times S^2\times H},$$

$$D_2=\frac{4\times C\times H^2}{8\times S^2\times H},$$

$$D_2=\frac{C\times H}{2\times S^2}. \tag{5}$$

LIST OF REFERENCES

1. United States General Accounting Office, High Risk Series, "Defense Inventory Management," Report GAO/HR-95-5, Government Printing Office, Washington, DC, February 1995.

2. United States General Accounting Office, High Risk Series, "Defense Inventory Management," Report GAO/HR-93-12, Government Printing Office, Washington, DC, December 1992.

3. United States General Accounting Office, High Risk Series, "Inventory Management: DOD Can Build on Process in Using Best Practices to Achieve Substantial Savings," Report GAO/NSIAD-95-142, Government Printing Office, Washington, DC, August 1995.

4. "The Eternal Burden," *Distribution Magazine*, November 1996.

5. Moore, Thomas P., and Alan W. McMasters, "Supply System Overview and Basic Inventory Management Concepts," Naval Postgraduate School, Monterey, CA, 1991.

6. Ballou, Ronald H., *Business Logistics Management*, 3rd ed., Prentice-Hall Inc., 1992.

7. DODINST 4140.39, "Procurement Cycles and Safety Levels of Supply for Secondary Items, 1991.

8. Tersine, Richard J., *Principles of Inventory and Materials Management*, 4th ed. Prentice-Hall Inc., Englewood Cliffs, New Jersey, 1994.

9. DODINST 4140.1-R, DOD Material Management Regulation, January 1993.

10. Cirello, Dominic, "Application of Just-In-Time Production Methods in the Defense Industrial Base," Air Force Institute of Technology, Defense Logistics Studies Information Exchange, September 1991.

11. Cheng, T. and S. Podolsky, *Just-In-Time Manufacturing*, 1st ed. Chapman & Hall, London, UK, 1993.

12. Schonberger, Richard S., *Japanese Manufacturing Techniques*, The Free Press, New York, NY, 1982.

13. Suzaki, Kiyoshi, *The New Manufacturing Challenge*, The Free Press, New York, NY, 1987.

14. Harrison, Alan, *Just-In-Time Manufacturing in Perspective*, Prentice-Hall International, London, UK, 1992.

15. Ansari, A. and B. Modarross, *Just-In-Time Purchasing*, The Free Press, New York, NY, 1990.

16. Harper, D. and K. Goodner, "Just-In-Time and Inbound Transportation," *Transportation Journal*, Winter 1990, Vol. 30, No. 2.

17. Chase, Richard B., and Nicholas J. Aquilano, *Production and Operations Management: A Life Cycle Approach*, 4th ed., Homewood, Richard D. Irwin, Inc., 1995.

18. Morgan, James P., "Who Says Just-In-Time Buying is only for Production?," *Purchasing*, February, 1996.

19. Heizer and Render. *Production and Operations Management*, 4th ed., Prentice-Hall, Inc., Upper Saddle River, New Jersey, 1996.

20. Telephone Interview with Mr. Gary Garner, Management Maintenance Configuration Assistant for the Strike Fighter Wing Atlantic, on 15 December 1997 and 17 December 1997.

21. Interview with Mr. Larry Whipple, Director for Aviation Support Division, Naval Air Station, Lemoore on 19 December 1997, 10 January 1998, 12 January 1998, and 26 January 1998.

22. Interview with Mr. Cheryl Haines, Item Manager, Defense Industrial Supply Center, Philadelphia, PA, on 22 January 1998, and 30 January 1998.

23. United States General Accounting Office, "Management of Secondary Items," Report GAO/NSJAD-93-112, Government Printing Office, Washington, DC, August 1993.

24. Sutton, Mathias J., "The Role of Electronic Data Interchange in the Transportation Industry," *Defense Transportation Journal*, August 1997.

25. Yano, Candace A., "Optimizing Transportation Contracts to Support Just-In-Time Deliveries: The Case of One Contracted Truck per Shipment," *JJE Transactions*, Vol. 24, No. 2, May 1992.

26. *FEDEX Service Guide*, Federal Express Corporation, 23 January 1998.

27. Hadley G. and T. Whitin, *Analysis of Inventory Systems*, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1963.

28. Vanairsdale, M., "Just-In-Time Inventory: Trading Efficiency for Effectiveness," *Army Logistician*, March-April, 1992.

29. Teresine, R., *Principles of Inventory and Material Management*, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1994.

INITIAL DISTRIBUTION LIST

No. Copies

1. Defense Technical Information Center 2
   8725 John J. Kingman Rd., STE 0944
   Ft. Belvoir, VA 22060-6218

2. Dudley Knox Library 2
   Naval Postgraduate School
   411 Dyer Rd.
   Monterey, CA 93943-5101

3. Jane N. Feitler, code SM/FJ 2
   Naval Postgraduate School
   Systems Management Department, code 36
   555 Dyer Road, Rm 210

4. Ataide R. Braga 6
   Brazilian Naval Commission
   5130 MacArthur Blvd. N.W.
   Washington, D.C. 20016-3344